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AIR BAG INFLATOR GAS JET EVALUATION
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INTRODUCTION

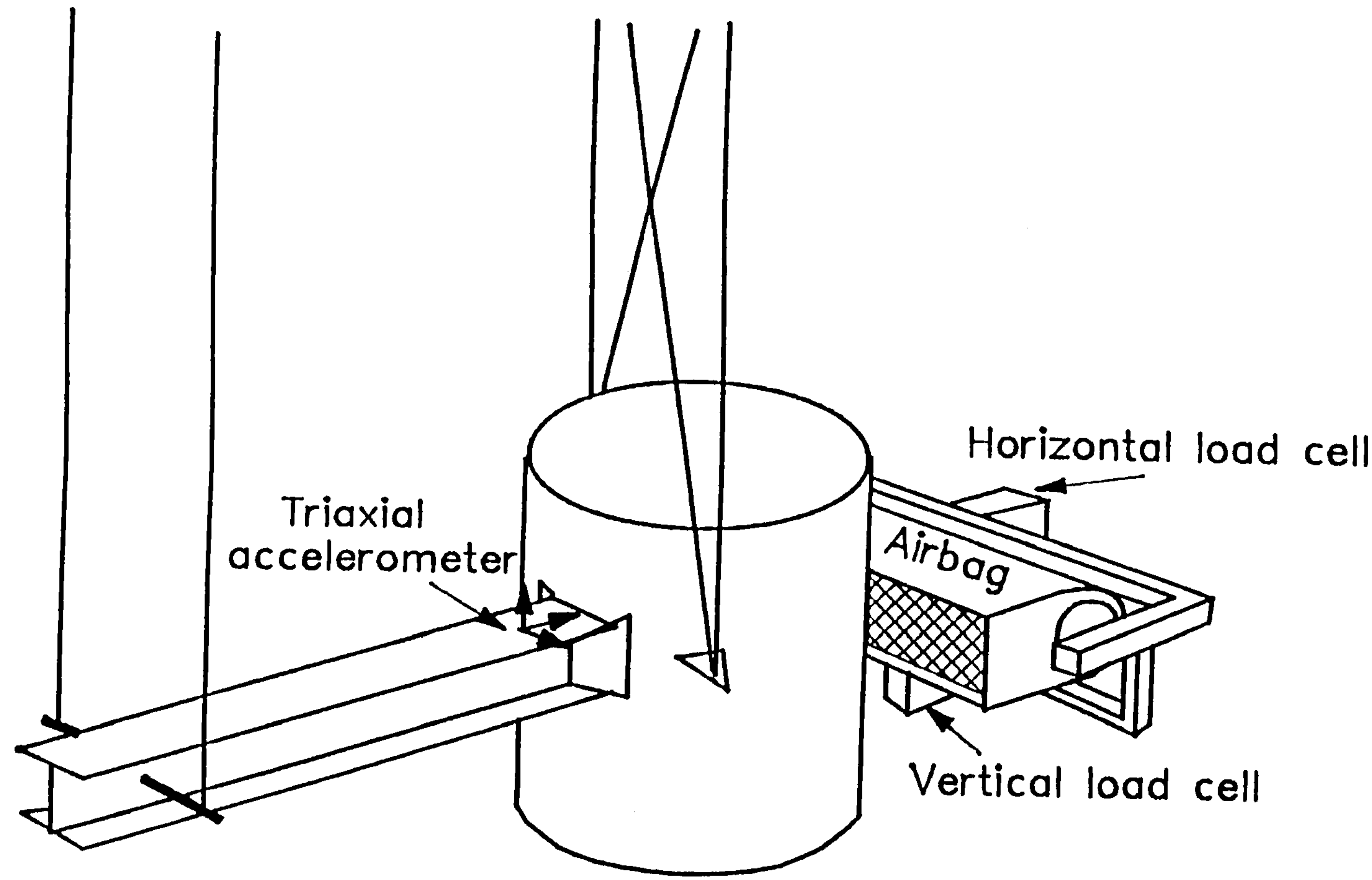
Most of the major automobile companies are developing an air bag system for both the driver and the passenger. The purpose of the air bag is to place, during a crash, in a timely manner, a "soft" cushion between the occupant and the hard structure inside the vehicle. Placing the air bag in position in a timely manner requires the air bag system to begin operation during the initial stages of a crash. A sensor must determine quickly that a crash is occurring and trigger the air bag launch. For the first 20-60 ms, the air bag is "deploying." During this deployment time, it is expanding very quickly. The rapid expansion ensures that it is in place and pressurized into a restraint pillow. When the occupant begins to move with respect to the vehicle, which is approximately 20-60 ms after the beginning of the crash, the airbag deployment process should already be completed or fully deployed.

What happens to an occupant when he interacts with a fully deployed air bag is reasonably well understood. However, a remaining concern, to safety engineers, is what happens to an occupant who is close to the air bag system and therefore makes contact with an air bag that is still deploying. The occupant may be close to the air bag system or in the path of deployment as a result of: his initial seating position, an acceleration, during the initial stages of the vehicle crash, which is below the sensor's detection threshold ability to detect during the initial stages of the vehicle crash or by pre-crash braking. To understand the results of an occupant's response to the deploying air bag, it is helpful to evaluate the forces acting on the occupant. One of those forces could be the wind-blast or gas jet effect.

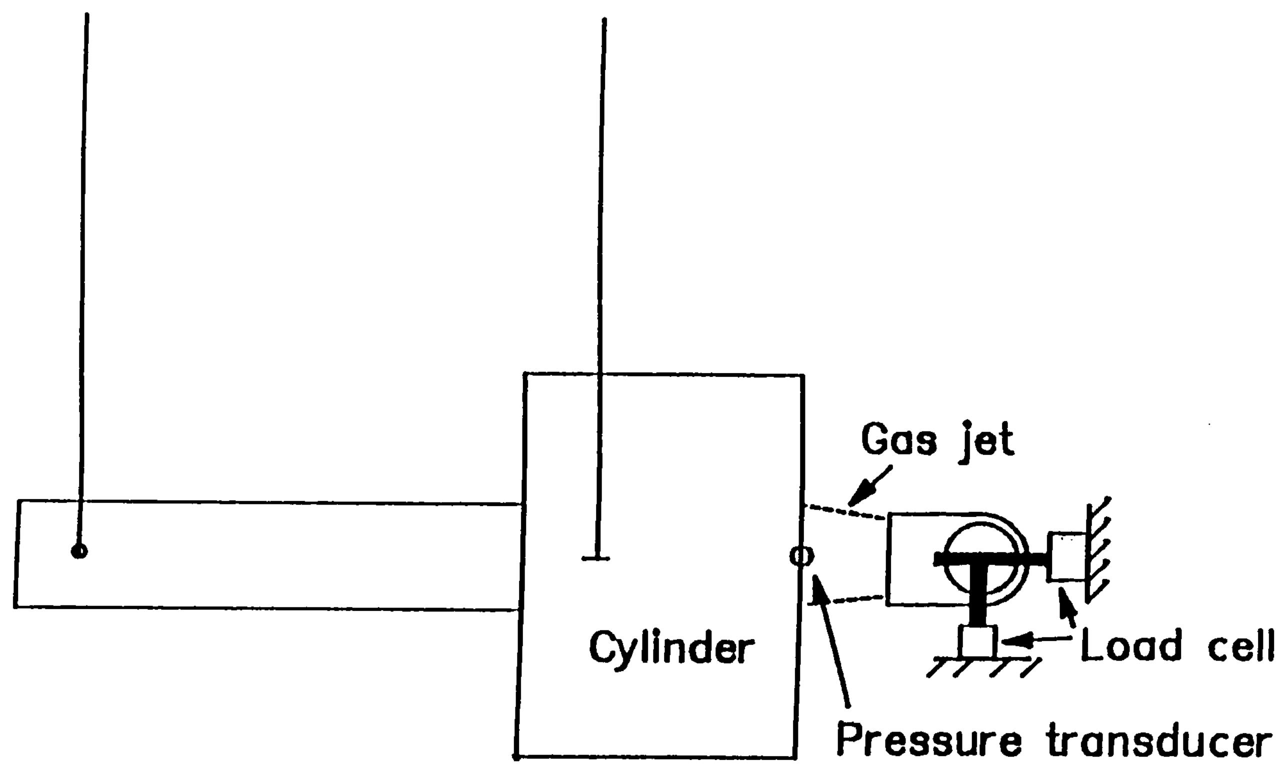
The wind-blast effect is the result of a high speed gas issuing from the mouth of the air bag canister. As a result of the gas density and its velocity, a momentum transfer takes place when the moving gas strikes an occupant, generating a force. The purpose of this paper is to present an experimental technique that can be used to determine the type of forces acting on an occupant as a result of the wind-blast or gas jet. In addition, to obtain a broader understanding, the windblast/gas jet effect has been investigated in two computer models: a lumped parameter and a finite difference model.

EXPERIMENTAL PROCEDURE

The system used to measure the gas jet forces (Figure 1), consists of a cylindrical drum fitted with a triaxial accelerometer. The cylinder is connected to an I beam which is suspended from the ceiling by overhead cables. The air bag system which consists of a housing (can), an inflator (gas generator), and an air bag fabric, is attached to a supporting frame fitted with two load cells to measure the forces in horizontal and the longitudinal directions (Figure 2). The air bag fabric is then removed from the air bag system to allow the gas jet to act directly on the drum. Finally, pressure transducers are screwed into the drum such that the stagnation pressure on the surface of the drum can be measured (Figure 2).



G.S. Nusholtz, Figure 1

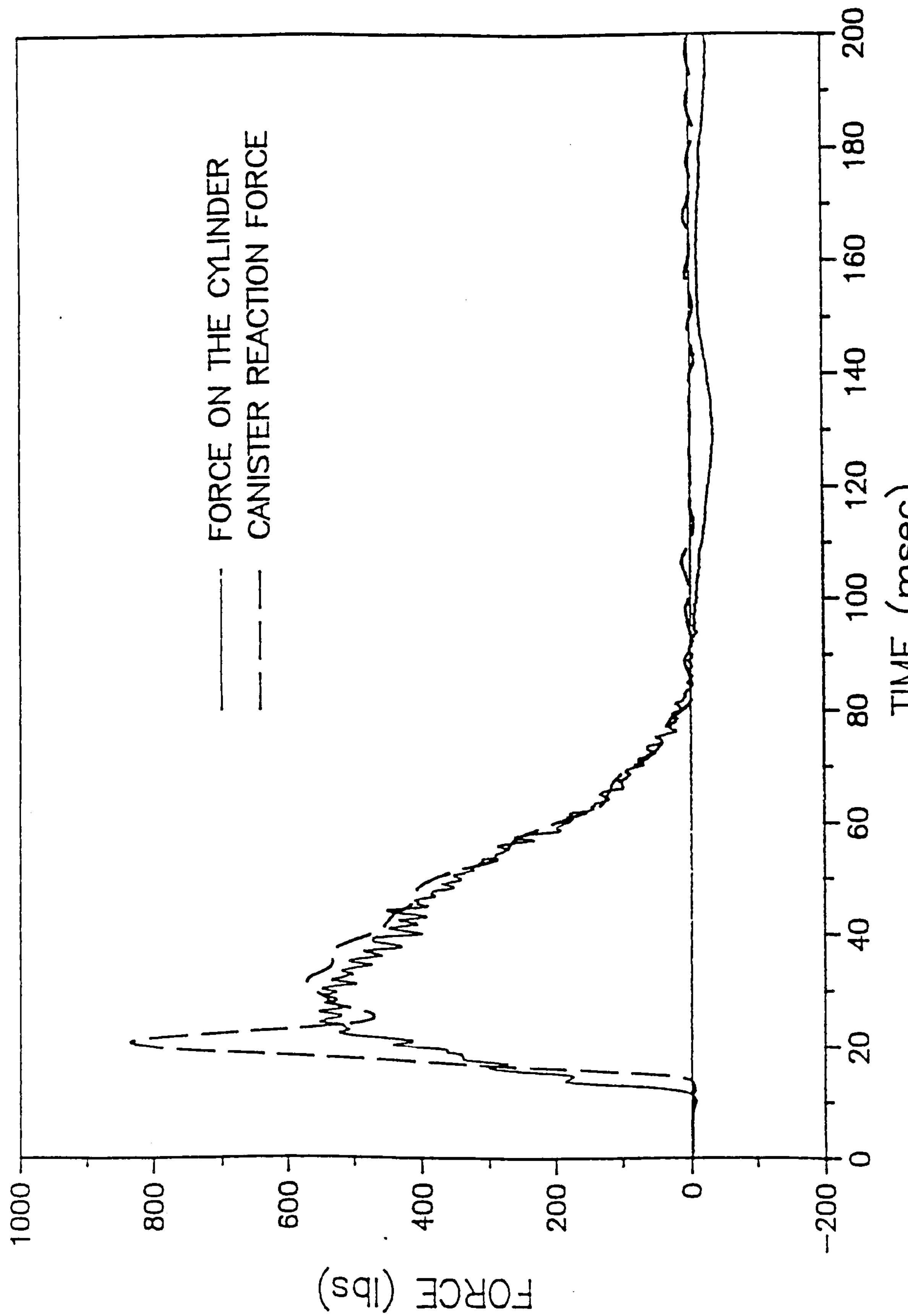


Side View

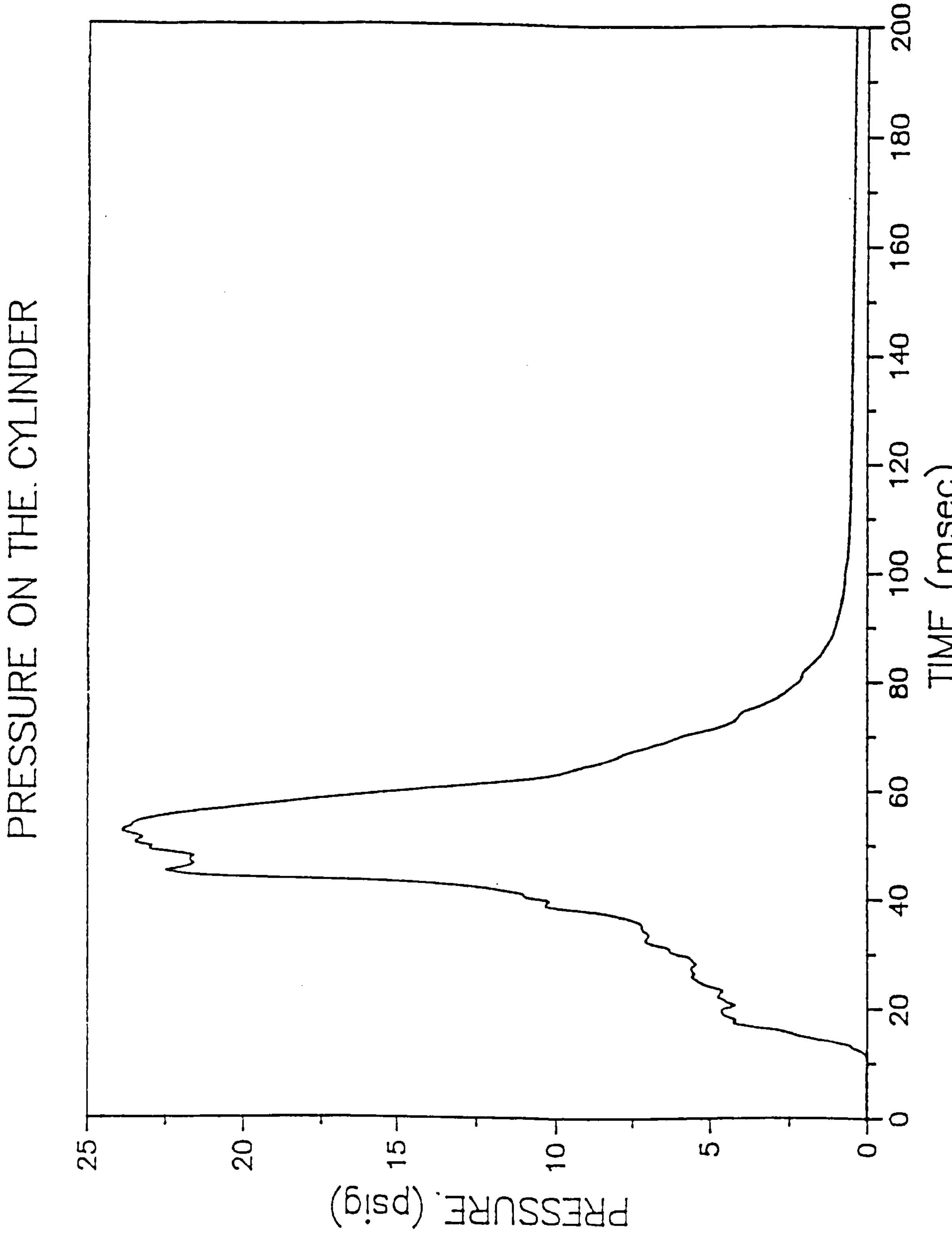
G.S. Nusholtz, Figure 2

With this configuration, the reaction forces of the housing can be measured directly. The force on the cylindrical drum can be estimated by multiplying the acceleration by the cylinder beam mass. Figure 3 shows the acceleration times the mass of the cylinder compared to the load cell force. In this test, the cylinder was placed initially 15 cm from the front of the air bag can. Surprisingly, these two forces are similar during the second half of the force time history pulse; implying that most of the energy is transferred to the cylinder. The initial large force measured on the housing is believed to be the result of differential motion between the inflator, which weighs 1 KG, and the housing and support. From the above example, it can be seen that about 2000 N is applied directly to the cylinder. This implies that for an occupant, 15 cm from the air bag, the forces could be of this magnitude.

It would be reasonable to assume that as a result of the wind-blast the acceleration/force of the drum would be similar to the average surface pressure times the contact area. However, a surprising result is obtained by comparing the pressure response of a point on the cylinder to the force on the cylinder (compare Figure 3 to Figure 4). Note that the pressure response time history shape is significantly different from that of the acceleration/force time history of the cylinder; i.e., the force and pressure peaks are out of phase. Although, the average pressure on the cylinder should be similar in shape to that of the acceleration time history the results indicate that: the pressure time history at different points on the



G.S. Nusholtz, Figure 3



G.S. Nusholtz, Figure 4

cylinder is very different from that of the acceleration time history.

MODELS

Through the use of the above test set-up, any air bag system's gas jets can be evaluated and insights into the forces acting on an out-of-position occupant can be obtained. In addition, the above experimental procedure can serve to help develop a model of an air bag that predicts the gas dynamics as well as the interaction of an occupant with a deploying air bag.

The following air bag models contain numerical procedures which attempt to address the gas jet effect. These models address the air bag system, such as: air bag membrane forces, leakage, and pressure effects as well as the gas jet effect.

These models are in the initial stages of development; therefore, even though they have been successful to date in predicting the force time history of the cylinder, they may not accurately represent the physics involved with the gas jet. There are two models presented; a two dimensional finite difference model of an air bag system, interacting with a dummy torso, and a non-buoyant gas jet solution which can be used in a lumped capacitance model.

2-D FINITE DIFFERENCE MODEL

Assumptions

The following principal assumptions are made to simplify the development of the numerical model of an airbag system interacting with a dummy torso. Brief discussions are included of the effects of these assumptions on the reality and accuracy of the numerical model.

(1) The flow regime in the air bag is two-dimensional, defined in the horizontal (x-y) plane. This means that the value of a variable represents, in fact, its average over the height of the airbag. The vertical (z-direction) flow in the airbag is ignored, but the effect of the leakage through the top and bottom of the airbag is taken into account by utilizing an adjusted equivalent leakage coefficient for the lateral porous skin.

(2) Throughout a transient analysis, the boundary (i.e., both the shape and position) of the airbag is fixed except the portion that is in contact with the moving torso. This allows the simulation of the airbag system without consideration of the airbag dynamics, which would make the analysis much more complicated.

(3) The torso is a moving rigid body. Without the airbag resistance, the acceleration of the torso would follow the impact pulse actually measured in the crash of a test vehicle without an airbag system. Throughout the impact, the minor axis of the torso coincides with the minor axis of the airbag.

(4) All the variables are symmetric about the minor axes of both the airbag and torso so that only one half of the system is modeled to save computer time.

(5) Gas density does not vary appreciably in the pressure range of interest (about 30% over a pressure range 0 to 6 psig). This assumption may affect the behavior of the impact-induced

transients. However, the discrepancy between the constant density and actual density is expected to be small during the high pressure portion of the impact, which begins with the full inflation of the airbag and ends with the stoppage of the gas inflow. In addition, the use of the equivalent input velocity that is transferred from the actual mass inflow rate based on the constant density also reduces the effect of the assumption.

Basic Equations

The transients in the airbag are simulated with the two dimensional characteristics-like method (Ref. 1). This section presents the equations applied in the current airbag model.

The two-dimensional gas flow in the airbag is governed by the following set of equations:

$$L_0 = u\frac{\partial p}{\partial x} + v\frac{\partial p}{\partial y} + \frac{\partial p}{\partial t} + \rho c^2\frac{\partial u}{\partial x} + \rho c^2\frac{\partial v}{\partial y} = 0 \quad (1)$$

$$L_1 = \frac{\partial p}{\partial x} + \rho u\frac{\partial u}{\partial x} + \rho v\frac{\partial u}{\partial y} + \rho\frac{\partial u}{\partial t} = 0 \quad (2)$$

$$L_2 = \frac{\partial p}{\partial y} + \rho u\frac{\partial v}{\partial x} + \rho v\frac{\partial v}{\partial y} + \rho\frac{\partial v}{\partial t} = 0 \quad (3)$$

$$L_3 = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} - \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) = 0 \quad (4)$$

In these equations, p, u, v are pressure and velocity components in x and y directions, respectively; t = time; ρ = the density of the fluid; and c = acoustic velocity. Equation (1) represents the conservation of mass condition with the isentropic relation $dp = c^2 d\rho$. Eqs. (2) and (3) are the momentum equations in x- and y directions.

In developing these equations, material properties are assumed to be time independent. Equ. (4), which merely states an identity, completes the set of equations.

A combination of these four equations using linear linear multipliers λ_1, λ_2, and λ_3 us carried out in the following manner:

$$L_0 + \lambda_1 L_1 + \lambda_2 L_2 + \lambda_3 L_3 = 0.$$

$$\left[(u + \lambda_1)\frac{\partial p}{\partial x} + (v + \lambda_2)\frac{\partial p}{\partial y} + \frac{\partial p}{\partial t}\right] +$$

$$\rho\lambda_1\left[(\frac{c^2}{\lambda_1} + u)\frac{\partial u}{\partial x} + (\frac{\lambda_3}{\rho\lambda_1} + v)\frac{\partial u}{\partial y} + \frac{\partial u}{\partial t}\right] +$$

$$\rho\lambda_2\left[(\frac{\lambda_3}{\rho\lambda_2} + u)\frac{\partial v}{\partial x} + \left(\frac{c^2}{\lambda_2} + v\right)\frac{\partial v}{\partial y} + \frac{\partial v}{\partial t}\right] - \lambda_3\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) = 0 \quad (5$$

Since ρ, u, and v are each functions of x, y, and t, this equation can be written as an ordinary differential equation if x and y become particular functions of time:

$$\frac{dx}{dt} = u + \lambda_1 = \frac{c^2}{\lambda_1} + u = \frac{\lambda_3}{\rho\lambda_2} + u$$

$$\frac{dx}{dt} = u + \lambda_2 = \frac{\lambda_3}{\rho\lambda_1} + v = \frac{c^2}{\lambda_2} + v$$

These equations can then be solved for ρ, u, v

NON-BUOYANT JET SOLUTION

Assumptions:

* Constant temperature
* Incompressible steady state flow with $\rho = 0.00128 \text{ slug/ft}^2$
* Non-buoyant jet solution with Gaussian profile

2-D Jet Model

Length of canister outlet >> width

Notation:

Gaussian Profile

$$v(x, z) = \hat{v}(z) e^{-(x/b_u)^2}$$

b_u - characteristic width, $v = \hat{v}/e$ at $x = b_u$

Jet Solution:

Volume flux (Δy = unity)

$$q = \sqrt{\Pi}\ \hat{v}\ b_u$$

$$m = \sqrt{\frac{\Pi}{2}}\ \hat{v}^2\ b_u$$

MODEL RESULTS

(1) Quasi-steady-state, non-uniform pressure distributions appear in the airbag domain during the transient events. The pressure increases from the canister outlet towards the left airbag boundary as the flow velocity decreases. The pressure difference depends mainly upon the input flow velocity, with a maximum value in the order of 2 psi. The non-uniform pressure distribution

results from the decreasing of the momentum that is carried by the flow.

(2) No significant pressure gradients are involved after the transient events associated with the wind-blast. This can be concluded by observing that the pressure at any point in the airbag varies smoothly until the dummy impact starts. Pressure gradients occur following the impact but do not exceed 0.2 psi.

(3) The lumped assumption that the pressure in the airbag is common at any time is considered to be acceptable if the effect of the Quasi-steady-state pressure difference can be taken into account properly.

(4) A simple yet effective way to include the effect of the non-uniform pressure distribution in a lumped airbag model is to add a momentum force to the total force acting on the torso. Experimental observations indicate that there is a high velocity gas jet that comes from the canister and traverses the airbag during the transient event. Such a gas jet does appear in the results from the two-dimensional models. It can be confirmed by fundamental jet flow theory as well. When the jet hits the wall of the airbag, the momentum carried by the jet is altered, generating a momentum force. This force acts on the wall and may be transferred further to the torso that contacts with the wall. The role of the momentum force is equivalent to the additional force due to the non-uniform pressure distribution.

SUMMARY

The objective of this study has been to evaluate the wind-blast/gas jet of an air bag system.The goal has been reached by developing an experimental procedure to measure the wind-blast/gas jet effect. Two-dimensional numerical model that simulates the dynamic response of the experimental procedure has also been developed. Comparisons have shown an acceptable agreement in general trends between numerical results and test records.

Appreciable discrepancies exist between numerical results and physical phenomenon, implying that the model is far from perfect. These discrepancies are due to the assumption of: two-dimensional flow, constant gas temperature and density, the omission of the effect of gas viscosity, and the exclusion of flow turbulence. An advanced numerical model of a lumped airbag system may be more desirable than the two-dimensional model to predict the dynamic response of the system with reasonable accuracy.

However, to understand, in a quantitative manner, the effect of the above assumptions on a model's abilities to accurately address the gas jet/wind-blast effect; an improved experimental procedure/procedures will be needed. The improved experimental procedure/procedures should address: three dimensional gas flow, rapidly changing gas temperature, gas viscosity, changes in gas density, and flow turbulence.

PAPER: THE EFFECT OF THE GAS JET IN AN AIR BAG SYSTEM

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No Questions asked.